INTERVENTIONAL CARDIOLOGY AND SURGERY

Radiation dose reduction without compromise of image quality in cardiac angiography and intervention with the use of a flat panel detector without an antiscatter grid

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Objective: To test the hypothesis that replacing the antiscatter grid with an air gap will reduce patient radiation exposure without significant compromise of image quality.
Methods: 457 patients having either uncomplicated diagnostic studies or a single vessel angioplasty (percutaneous transluminal coronary angioplasty (PTCA)) on a flat plate system (GE Innova) were studied. For two months their total dose–area product score was recorded on standard gridded images and then for two months on images made with the grid out, with an air gap used to reduce scatter. Detector magnification was reduced one step when an air gap was used to achieve the same final image size. A sample set of studies was reviewed blind by five observers, who scored sharpness and contrast on a non-linear scale.
Results: The average dose–area product was significantly reduced, both in the diagnostic group (n = 276), from a mean (SD) of 26.2 (14.7) Gy·cm^2 with the grid in to 16.1 (12) Gy·cm^2 with the grid out (p = 0.01), and in the PTCA group (n = 181), from 48.2 (36.2) to 37 (27.5) (p = 0.01). The mean image quality scores of the gridless cohort were not significantly different from those of the gridded cohort.
Conclusion: With the use of a flat plate detector, air gap gridless angiography reduces the radiation dose to the patient and, in consequence, to the operator without significantly affecting image quality. It is proposed that gridless imaging should be the default technique for adults and children and in most installations.

Scattered radiation from the patient degrades image contrast in most forms of radiography. It is reduced (but not eliminated) in most installations by the use of an antiscatter grid. However, the grid not only clears scatter but also blocks some of the primary beam (fig 1). As a result, the use of a grid usually doubles the patient's exposure. In the child, radiation is less scattered and it is standard practice in some departments not to use an antiscatter grid.[1] In the adult, some form of scatter reduction is generally required.

There is an alternative to a grid: an air gap of 15 cm or more between patient and detector allows dissipation of much of the scatter and does not compromise the primary beam (fig 1). The resultant image is magnified, but not by more than one step in ordinary intensifier or detector electronic magnification. Provided that the magnification geometry does not induce focal spot unsharpness, the resultant image should be as good as a gridded image but at a reduced exposure. A 15 cm air gap does not generate unsharpness if the tube is on fine focus (0.6 mm or less). Broad focus can be from 0.8 to 1.2 mm depending on tube type. Even with 1.2 mm, a 15 cm gap is unlikely to cause significant unsharpness. This must be verified for each tube if the technique is to be used. It is also important to keep the heart at or above the isocentre of the gantry (which is good practice in any event). With flat panel detectors, air gap magnification projects the image on to a greater number of pixels, which partially compensates for the focal spot effect.

It follows that for any investigation where electronic magnification is used, replacing a level of magnification with an air gap achieves a reduction in patient dose. If patient dose falls, so does the scattered dose to the operator. In large patients, because of the loading characteristics of *x* ray tubes,

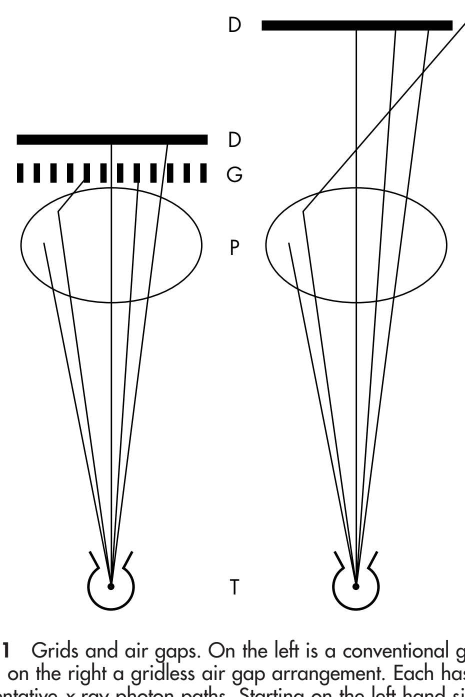

Figure 1 Grids and air gaps. On the left is a conventional gridded system, on the right a gridless air gap arrangement. Each has five representative *x* ray photon paths. Starting on the left hand side, both have a photon which is absorbed completely. The next is a scattered photon, which either is removed by the baffles of the grid or, on the right, misses the detector altogether by virtue of its angulation across the air gap. The other three are all primary image forming photons but in the gridded image one of them has been removed by the grid itself. D, detector; G, grid; P, patient; T, *x* ray tube.

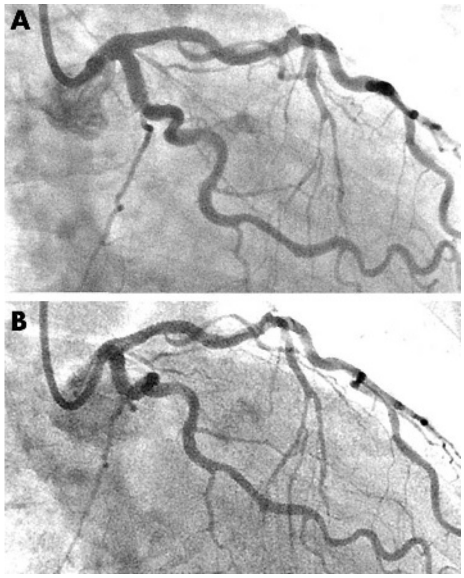

Figure 2 Images of the solitary patient who had the grid reinserted. The upper frame is the run immediately before the grid was replaced and the lower is the one after. The ungridded image has slightly less contrast than the gridded, and vessel sharpness is not significantly different.

a reduction in dose lowers the operating kilovoltage, which improves image contrast.

In a pilot study of 33 patients, Partridge *et al*[2] validated the gridless technique with the use of a General Electric Innova flat panel system (General Electric, Slough, Berkshire, UK). In this series and on the same equipment, a larger group of patients were studied to further test the technique.

METHOD

For two months, uncomplicated coronary angiography and single vessel angioplasty with a gridless air gap technique were consecutively studied. All images were acquired at 12.5 frames/s. Phantom studies had shown that the equipment selected its largest (approximately 1.0 mm) focal spot for adult angiocardiography on magnified images. They also showed that an air gap of 15 cm would not cause significant geometric unsharpness on a broad focal spot, and the geometric enlargement generated was the same as a single field step on the detector. The operator was instructed to use one less field size than the usual setting, thus ensuring that the final image was of the usual overall magnification. The total patient exposure was recorded as the dose–area product in $Gy{\cdot}cm^2$. The operator could not be blinded for the study, as the change in technique was obvious. To safeguard patient treatment, any operator could at any time require the grid to be reinserted if he or she thought that image quality was non-diagnostic. Results of the two groups were compared with the results obtained during the preceding two months in which our standard technique was used for the same types of procedures. The operators were a consistent group for both periods.

Three cardiologists, two cardiac radiographers, and one cardiac radiologist reviewed the angiograms. The reviewers were blinded to the technique used and reviewed 36 studies, the nine with the highest and nine with the lowest doses in each of the two classes. Each observer graded each study as a whole. Image contrast and sharpness were separately scored as 1 (good), 2 (satisfactory), 3 (poor but diagnostic), or 4 (non-diagnostic), and the image quality score was the sum of the two. A score of 2 would therefore be the best possible and 8 the worst. The mean of the scores of the six readers was calculated.

As we were applying a standard radiographic technique and radiation dose could not increase because of it, no ethical approval was required.

RESULTS

During the gridless period, the operator required the grid to be reinserted only once. Figure 2 shows representative images before and after insertion.

Exposures

Table 1 summarises the results. The figures for mean weight and height show that the groups were comparable. Radiation doses were compared by simple Student's *t* test. Radiation exposure was significantly reduced in the gridless group during both diagnostic and interventional studies.

In terms of image quality, no study was graded as non-diagnostic. The average score for the gridded group was 2.78 (range 2–3.8) and for the air gap group it was 3.08 (range 2.0–5.0). This difference was not significant.

Figures 3–7 show sample images. Figure 3 is from a patient who happened to have a check diagnostic study after the series was finished, having had a percutaneous transluminal coronary angioplasty in the gridless group. The left anterior oblique cranial view was of very similar orientation in both and provides a comparison in one patient. All the other figures are of representative types and are provided as an illustration rather than to show the analysis.

DISCUSSION

In the UK, there is a statutory obligation to minimise radiation dose to both patient and operator while maintaining adequate image quality. Many authors have emphasised the need to ensure that equipment is safe and efficient, to use appropriate tube filtration, and to show skill in the selection of exposure parameters[3–6] Relatively little had been written about the antiscatter grid.

Onnasch *et al*[7] measured doses with and without grids, and confirmed that removing the grid usually halved the dose. They did not use an air gap, however, and as a result found decreases in signal to noise ratios due to increased scatter. They advocated the use of a grid even for the infant, though the improvement in signal to noise ratio was never more than

Table 1 Summary of results of the four series

	Diagnostic procedures			PTCA		
	Grid in	Grid out	p Value	Grid in	Grid out	p Value
Number	154	122		102	79	
Dose ($Gy{\cdot}cm^2$)	26.2 (14.7)	16.1 (12)	0.01	48.2 (36.2)	37 (27.5)	0.01
Fluoroscopic time (min)	2.7 (1.9)	2.6 (1.9)		8.1 (5.3)	8.9 (5.2)	
Height (m)	1.7 (0.1)	1.7 (0.1)		1.7 (0.1)	1.7 (0.1)	
Weight (kg)	80.5 (16)	78.8 (15)		80.9 (15)	82.4 (15)	

Data are mean (SD).
PTCA, percutaneous transluminal coronary angioplasty.

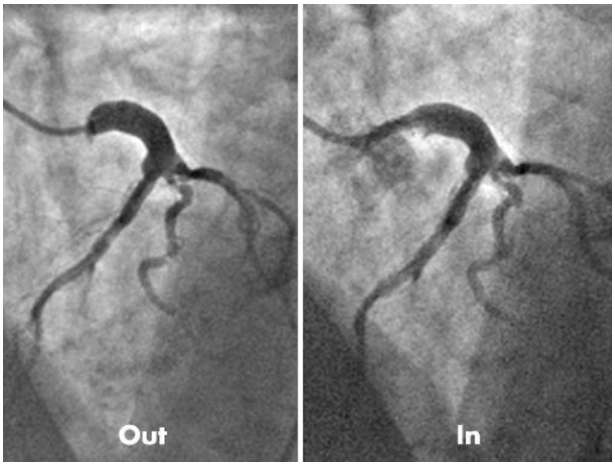

Figure 3 Two studies, one with the grid in (In) and one with the grid out with an air gap (Out), from the same patient.

27% despite a doubling of dose, which we regard as a debatable advantage. When an air gap is added scatter is reduced, and we have shown here that image quality is maintained at a satisfactory level. As the dose to the patient is reduced, so is the secondary exposure of the operator.

At the outset there were reservations that the traditional emphasis on keeping the detector or intensifier close to the patient had to be abandoned. Fears that the air gap would allow more scatter to be distributed on the exit side of the patient should be dispelled by the fact that the main source of scatter is the input side of the patient. The gap would increase the overall dose in classic radiography but this effect is removed by reducing the amount of electronic magnification. There was justifiable concern that focal spot unsharpness would be a problem. This was certainly the case in years gone by when angiographic tubes had large, blurry focal spots. Present day tubes have medium sized spots, and the intensifiers and flat plates have enough inherent unsharpness of their own that they are the major source of

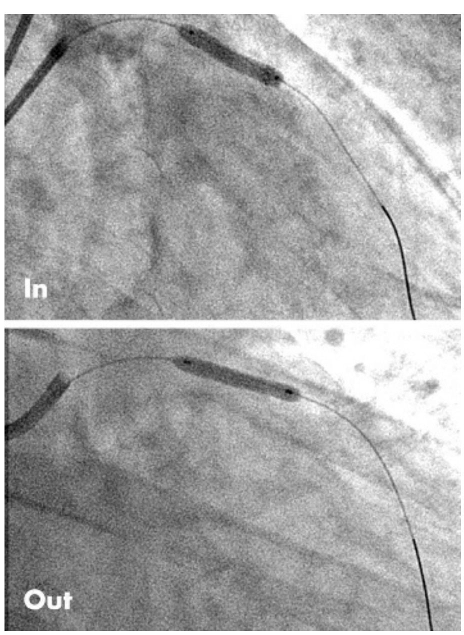

Figure 4 Percutaneous transluminal coronary angioplasty balloons and wires in two small patients.

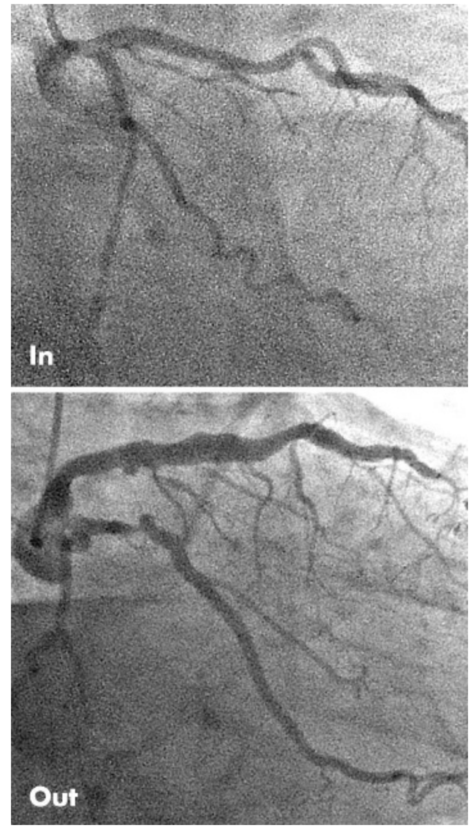

Figure 5 Diagnostic studies in two large patients showing the right anterior oblique caudal view of the left coronary artery.

unsharpness in most circumstances. This series was not undertaken until a line-pair phantom test had shown that the air gap produced minimal unsharpness. We acknowledge

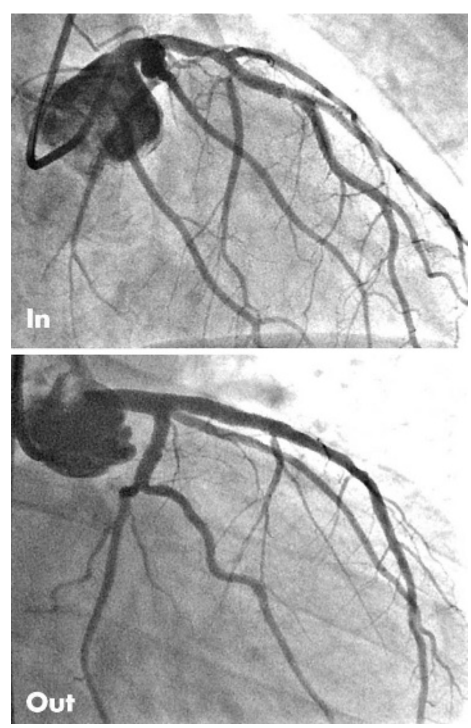

Figure 6 Diagnostic studies in two small patients showing the right anterior oblique view of the left coronary artery.

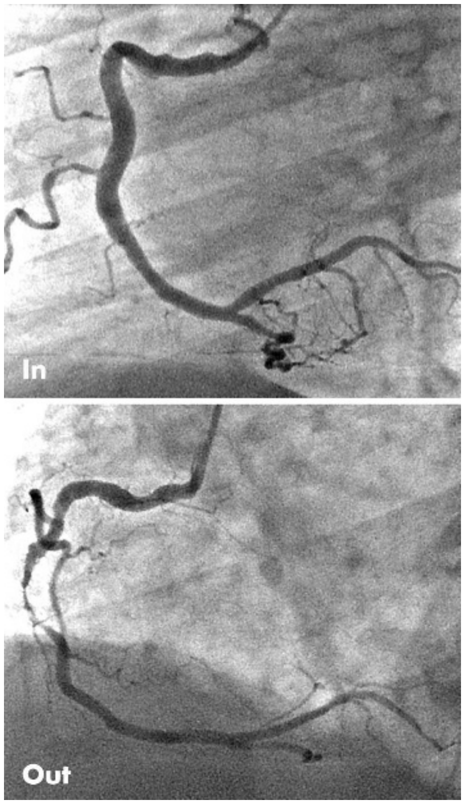

Figure 7 Diagnostic studies of the right coronary artery in two large patients in the right anterior oblique view.

that this paragraph is a simplification of the physics, but we hope that the results speak for themselves.

There is a theoretical argument to say that we experienced a smaller degree of dose reduction than might be expected. One can hope for a halving of dose at least when a grid is removed. Most of the answer lies in the software control of the flat plate. Many installations nowadays limit the increase in beam intensity that usually accompanies the use of smaller field areas. The Innova system goes further, and dose is subject to variation depending on image characteristics. If the control had been removed then the gridless doses would have been even lower. There is a case for lowering the exit dose requirements for geometric magnification.

We were not in a position to assess separately the effect of an air gap on fluoroscopy, as the dose was an aggregate and fluoroscopic images could not be retained for analysis. The operators made no adverse comment. In theory focal spot unsharpness should be less than on acquisition, as all fluoroscopy is done on the tube's fine focus. The air gap also has the effect of making an extra step of magnification available (that is, maximum electronic magnification plus air gap). This may be of occasional help in interventional work.

Conclusion

We conclude that gridless angiography should be the default technique for coronary angiography and intervention with the current generation of flat plate detectors, electively returning to gridded images as an occasional response to poor contrast in very large patients. It could equally be applied to image intensifiers, provided that each installation undergoes a simple test on the effect of the air gap on focal spot unsharpness (table 2) Even if this fails, interventional fluoroscopy on fine focus would still be satisfactory.

Table 2 How to set up a gridless technique

1	Make a note of your usual FDD in ordinary operation and of your usual magnification setting for coronary work
2	Put a line-pair phantom on to the table and screen it into the isocentre, and set your usual FDD and magnification
3	If a focal spot can be chosen, set a broad focus
4	Load the tube with a sheet of 1 or 1.5 mm copper
5	Make an exposure
6	On the monitor, measure the size of your phantom
7	Select one step less electronic magnification
8	Fluoroscope while you increase the FDD until the phantom is the same size as in step 5. Note the new FDD
9	Remove the grid
10	Make an exposure
11	Process and view the images. If the air gap image from step 10 is not significantly blurred and the difference between the FDDs is 15 cm or more, your system is good for gridless technique

FDD, focus to detector distance.

The principal exception would be when the coverage of the image needs to be the maximum, such as in arch aortography, as maximum coverage by the detector can only be realised when it is close to the patient. This is not the case with left ventricular angiography, which can usually be done on the first step of magnification. When image quality is not critical—for example, in electrophysiological fluoroscopy—full field gridless images without an air gap are usually still adequate.

Our observations were made in the adult. The principle can be extended directly to paediatric work; there is no practical or theoretical reason why the benefit should not be greater.

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